

# Exhibit 22

(Amended)

# CHAPTER V. ORE DEPOSITS NEAR CONTACT OF MASSIVE AND LAYERED ROCKS

## *Part I. With faults, fissures or shear zones*

### C. STRIKE UNCLASSIFIED

#### BRALORNE, B.C., OREBODIES

BY IRA B. JORALEMON\*

**I**n the Bridge River district of British Columbia lenses of augite diorite several miles long and several thousand feet wide cut Cretaceous and Carboniferous sediments and greenstone. The sediments in the part of the district near the Bralorne mine are chiefly thin bedded chert and shale. Dikes of serpentine sometimes follow the diorite-sediment contacts and sometimes cut the sediments.

Bralorne orebodies are in persistent quartz veins that cut diagonally across the diorite into the sediments and greenstone. The walls of the largest orebodies are diorite, though some ore is found where walls are sediments.

Fine grained aplite or albitite dikes, somewhat earlier than the quartz but seeming to grade into it in places, frequently accompany the veins. Similar dikes occur in places away from veins. Alteration of vein walls, whether diorite, greenstone, or sediments, in places resembles the aplite so closely that the two can not be distinguished. Microscopic study has not yet succeeded in solving the problem.

Most of the veins are nearly parallel, striking within a few degrees of east-west and dipping 45° to 75° north. There are several north-south cross veins, one of which contains valuable orebodies. The east-west veins are displaced by several thrust faults with a displacement of 100 to 400 ft. One of these faults follows the orebearing north-south "C" vein. There is frequently post-ore movement and gouge along the east-west veins also. The total displacement along these fissures, including pre-ore and post-ore faulting, is from a few feet to several hundred feet.

Ore consists of quartz or silicified aplite, with 3 or 4 per cent of pyrite and arsenopyrite, and minor amounts of sphalerite, galena and other sulphides. The gold is largely free, averaging about 0.4 oz. per ton. Orebodies are generally 3 to 8 ft. wide and several hundred feet long. One orebody is much larger, reaching a maximum width of 60 ft.

No general reason for localization of orebodies has yet been found. Usually any complexity is favorable. The large "A" orebody in the King Vein is accompanied by the following structural conditions:

1. It is near the west border of the diorite.
2. Near the ore the aplite (or aplitic alteration) that accompanies the vein expands into a body 100 ft. wide.
3. Where the east-west King Vein meets the north-south "C" Vein, this aplite is thoroughly shattered and largely

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replaced by gold bearing quartz, converting nearly the whole mass into ore.

4. The north-south "C" vein and the post-ore fault that follows this vein dip west, and form the west limit of the "A" orebody down to the 9th level. Down to this same level the "C" vein and fault, in the area near the "A" vein, mark a contact between diorite on the east and serpentine on the west. The richest part of the "A" orebody is accordingly just across the "C" vein from the serpentine. Below the 9th level the serpentine contact crosses into the footwall of the "C" vein and becomes vertical. At greater depth the "A" vein plays out in small stringers in the serpentine, and does not extend as far west as the "C" fault. The "C" vein also is barren where both walls are serpentine. The west end of the "A" orebody is no longer large and rich below the 9th level as it was on upper levels where it met the west-dipping "C" vein. It seems that an "overhanging" serpentine contact had an important bearing on the fine "A" orebody above the 9th level.

The reasons for other orebodies are not apparent. Several occur near contacts of diorite with greenstone or sediments where the vein is bent in a flat bow. But one of the best orebodies is far within the diorite, with very little aplite or alteration of walls, at a place where the fissure is almost perfectly straight on the developed level.

#### VERMONT TALC AND ASBESTOS DEPOSITS

BY G. W. BAIN\*

##### GENERAL FEATURES

**V**ERMONT talc deposits<sup>1</sup> occur in saxonite and dunite intrusives outcropping along a zone between North Troy on the Canadian border and Chester in Massachusetts. They follow closely the contact between the western pre-Cambrian gneisses and isolated areas of Cambro-Ordovician sediments to the east. All structural planes in this zone incline downward to the west. Asbestos is associated with the northern ultrabasics and occurs in a position complementary to that occupied by talc.

The ultrabasics may belong to at least two ages. Cambro-Ordovician quartzite seems to overlie the intrusives non-conformably at Rochester and pebbles of ultrabasic rock occur in an Ordovician conglomerate at Trowser's Lake, Que. Other ultrabasic masses intrude the Cambro-Ordo-

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<sup>1</sup> For distribution see, Bain, G. W., Serpentinization of Vermont ultrabasics: Bull. G. S. A., 47, p. 1966, 1936.



vician slates of the Missisquoi Valley. However the Montegregian sub-alkaline intrusives cut all essential structures of the deposits at a number of places.

#### ALTERATION

A study of the characteristic alteration about the ultrabasic bodies clarifies many structural features. Three rock types are in contact with the ultrabasics; they are tuff and associated volcanics, quartz sericite schist or gneiss, and slate. Mineral change in the wallrock is proportional to change in adjacent ultrabasic; it is negligible where the ultrabasic is more than 25 per cent olivine, may appear as a one foot chloritized zone adjacent to thoroughly serpentinized rock, and may extend outward for 20 ft. from a completely steatitized mass. Variation in wall alteration along the same contact of the same intrusive equal to that along contacts of different intrusives favors an external origin for solutions and a structural control of their movement. The occurrences suggest that wallrock and intrusive were affected simultaneously and then only after both were a receptive conduit for external solutions.

Mineral transformations show diminution of FeO and MgO in intrusives and enrichment of wallrock in these same substances;  $\text{Cr}_2\text{O}_3$  is reduced in steatitized sections and increased in serpentinized zones. The alteration is not a simple interchange across the contact to attain balance but is an expulsion of material from the ultrabasic by alkalic solutions entering it. This is illustrated by an extreme case at Trowser's Lake in Quebec where the wallrock has been transformed to a chlorite schist and the ultrabasic has become a microcline-albite-quartz rock with about 5 per cent of muscovite and anthophyllite. The mass inherits the ultrabasic fracture pattern and vein structures but in all other features appears to be a granite.

Characteristic ultrabasic alteration is divided into three stages. The first is a simple autometamorphic serpentinization. Antigoritization is later and in this belt always accompanies and is accompanied by tectonic movements in thoroughly crystalline ultrabasics. Formation of chrysotile asbestos, talc and associated minerals is usually the last change in the sequence.

#### EXTERNAL STRUCTURAL RELATIONSHIPS

Most ultrabasics here are nearly vertical lens-shaped bodies with axes inclined slightly to the west and pitching to north or south; one on Belvidere Mtn. seems to be a phacolith (Fig. 1).<sup>2</sup> Characteristically talc occurs at one end of a mass and serpentine or saxonite at the other. A few are talc throughout and at least two have talc at both ends with serpentine in the middle. Mining, quarrying and core drilling show that the main talc bodies are principally along the keel of the lenses, as at the Duxbury, Rochester and Stockbridge deposits (Fig. 2). Small deposits follow upwards along the walls and fracture zones within the ultrabasic, as at the Stockbridge and Roxbury deposits.

The serpentine-talc contact is irregular but relatively sharp and always distinct. Most structures of the original serpentine have their original size and form although simple chemical alteration of serpentine to talc calls for great volume increase. The change is regarded as alteration at constant volume wherein the excess serpentine is removed by the steatitizing solutions. Some minor amount of the

<sup>2</sup> For map see also Keith, S. B., and Bain, G. W., Chrysotile asbestos: Econ. Geol., vol. 27, p. 177, 1932.

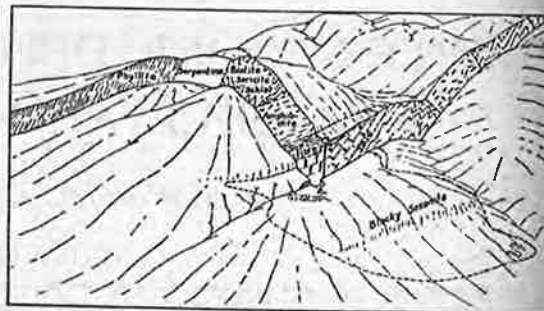


FIG. 1. Diagram showing the talc-slip fiber relations near the Vermont Asbestos Corporation's mine at Belvidere Mtn. Top of the diagram is to the northwest. Note the talc deposit pitching under the ultrabasic, the slip fiber deposit near the top at the upper left and pits of the cross fiber deposits at the lower right.

serpentine constituents pass outwards to cause chloritization of the wallrock but the major portion appears only as veins of asbestos in the blocky, upper part of the ultrabasic.

#### INTERNAL TEXTURES AND STRUCTURES

Bent fiber chrysotile asbestos veins, fibers partly bent and partly straight, and cross fiber veins almost converted to slip fiber in among simple cross fiber veins, all indicate active but not excessive movement among the serpentine blocks during asbestos formation. Movements of comparable magnitude appear in the talc bodies.

#### STRUCTURAL CONTROL OF THE SOLUTIONS

Distribution of alteration products in the ultrabasic indicate that solutions ascended along the same tectonic axes as the ultrabasics. The alteration products indicate that the solutions had initially alkalic rather than femic composition. During ascent they encountered the ferromagnesian minerals and reacted with them to become impotent except where they passed beyond the ultrabasic boundaries. The alteration minerals produced, follow the ordinary hydrothermal reaction series. The spent solutions in equilibrium with serpentine moved through fractures of the ultrabasic and deposited their serpentine in asbestos-form in gradually widening cracks.

The general relations of talc and serpentine to solutions, tectonics, and to structural position in an ultrabasic intrusive as summarized above are illustrated by a number of Vermont deposits. Every ultrabasic intrusive has a talc deposit and about one-third have some fibrous magnesian mineral. Only a few occurrences are described and the reader is referred to the bibliography for additional details. The occurrences illustrate progressively increased intensity of change from talc and asbestos in proportionate amounts at Belvidere Mtn.,<sup>3</sup> to completely steatitized bodies at Chester and Windham.

#### BELVIDERE MTN. ASBESTOS DEPOSIT

A warped but nearly horizontal tabular ultrabasic mass outcrops on the southeast side of Belvidere Mtn. (Fig. 1). Asbestos occurs in commercial amounts in the upper part of the intrusive near its western and eastern extremities. The western deposit has slip fiber whereas the eastern one contains only cross fiber. The northern tip or underside of the ultrabasic is altered to talc-carbonate rock and is in

<sup>3</sup> Keith, S. B., and Bain, G. W., op. cit., p. 287.



the same sheared zone as the slip fiber deposit but structurally below it.

The elements in formation of asbestos are three in number:

1. A primary alkalic solution ascending along the same tectonic plane as the ultrabasic.
2. Attainment of equilibrium with the ultrabasic and saturation with serpentine.
3. Ascent along tight shear zones to slowly opening fractures in the blocky, competent, upper part of the ultrabasic.

Major tectonic planes control ascent of primary solutions to the ultrabasic. The ultrabasic itself furnishes the serpentine by entering solution in order to maintain the constant volume relationship in the steatitization process. This serpentine is reprecipitated only where the fissure walls tend to open under influence of tectonic forces and where solution equilibrium existing in the narrow openings of the deeper steatitized and serpentinized mass is disturbed. These same elements appear in all the ultrabasic bodies and their significance is recognized readily from their spatial distribution.

#### JOHNSON AND WATERBURY TALC DEPOSITS

These talc deposits are in huge lenticular bodies between walls of chlorite schist.\* The original ultrabasic character is evident but the entire body has been steatitized. Structural control of the deposit is obscured by completeness of the change.

#### BISBEE MINE, DUXBURY TALC DEPOSIT

The talc deposit outcrops at the south end of a mile long lenticular ultrabasic and pitches north at about 30° along the keel of the mass. (See Fig. 2; for map see Keith, S. B., & Bain, G. W., *op. cit.*, p. 291.) The deposit has the form of the hull of a ship with a greatly thickened keel. Most talc formed by alteration of the ultrabasic intrusive is adjacent to the slightly steatitized chlorite schist walls. The sides of the ship-shaped talc body taper upwards to a very thin talcose sheet between the central serpentine and talc schist wall. Talc extends farther north on the eastern wall than on the western one. Since the axial plane of the ultrabasic lens inclines downward to the west, the east side is the under side of the lens.



FIG. 2. Block diagram showing talc-serpentine-chrysotile relationships in the Duxbury-Moretown ultrabasic. The top is towards the west.

Bisbee talc mine operations extend under the serpentine at the extreme left. Chrysotile veins occur in serpentine and serpentinized peridotite at the extreme right. The shear zones are rich in magnetite and chromite.

\* Gillson, J. L., *Origin of Vermont talc deposits with a discussion of the formation of talc in general*: *Econ. Geol.*, vol. 22, pp. 246-287, 1927; Jacobs, E. C., *Talc and talc deposits of Vermont*: 9th Rept. Vermont State Geol., pp. 382-429, 1914.

Thin bands of cross-fiber asbestos occupy veins at the north end of the ultrabasic or end distant from the talc. Many are one-half inch wide but do not come in sufficient number to be of commercial importance. Shear zones through the ultrabasic, between the talc at the south end and the cross-fiber veins at the northern extremity, are thoroughly serpentinized and have abundant magnetite and chromite grains along them.

Another ultrabasic mass of smaller size occurs about one mile south of the Bisbee mine and exhibits identical relationships.

#### ROCHESTER TALC MINE

The mine is located about two miles from the town at the southeast corner of Rochester Hollow. The deposit is in an ultrabasic body whose axis inclines downward to the west so that the east flank is the under side. The shaft follows the keel of the ship-shaped deposit downward at an inclination of about 30° to the north. The talc body extends farther northward along the east or under flank of the ultrabasic than along the western edge.

Asbestos is present around the north end of the mass but is not abundant. It does not appear through the central section.

Intensive core drilling at the Rochester verde antique quarry, 3 miles to the north, discloses similar talc-ultrabasic spatial relationships. Asbestos is uncommon but veins of columnar magnesite are abundant in the north end or end distant from the talc body.

#### GREELY TALC MINE, STOCKBRIDGE

An ultrabasic mass with a westward dipping axial plane outcrops on a steep hillside west of the White River. The keel of the ship-shaped mass pitches northward from the hilltop at about 800 ft. south of the mine to the valley floor at the mine entrance. The talc body occurs along the keel of the mass and also in and along a stockwork of veins through the center. These stockwork deposits have never proved important although they have been explored carefully at this mine and in many of the serpentine marble deposits.

#### THE CHESTER TALC MINE

An ultrabasic outcrops about 1½ miles west of Chester, Vt. The axial plane dips slightly west from the vertical. Most of the mass is steatitized and residual serpentine remains only at the north end which is most distant from the keel of the mass and especially towards the west or upper side (Fig. 3).

The gneiss and feldspathic schist walls show significant zoning. The outer zone has the same minerals as the country rock but is enriched in ferromagnesian minerals such as biotite and tourmaline. A chlorite zone lies inside the biotite zone and occasionally extends up to the talc; less often a thin band of undeformed actinolite, crystallized subnormal to the wallrock contact, intervenes between the biotite or chlorite schist and the talc. Adjacent talc penetrated by the acicular actinolite is highly deformed. The actinolite ends spray out into fine needles and skeletal groups are abundant. Hess refers<sup>5</sup> the talc cores of these skeletal groups

<sup>5</sup> Phillips, A. H., and Hess, H. H., *Metamorphic differentiation at contacts between serpentinite and siliceous country rock*: *Amer. Miner.*, vol. 21, p. 345, 1936.

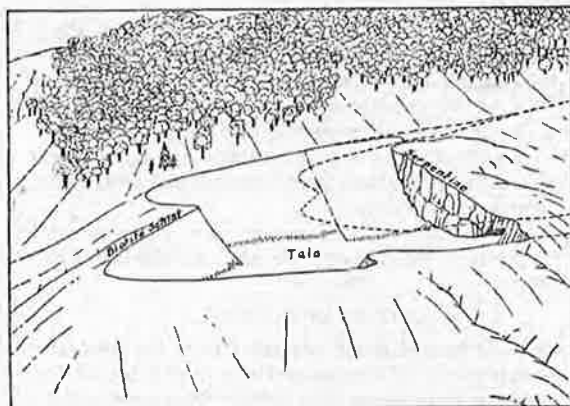


FIG. 3. Sketch of the Vermont Mineral Products mine at Chester, Vt. The main talc body pitches northward (to the right) under serpentine containing only minor steatite. The talc and actinolite rock are stripped back to the biotite schist zone surrounding the ultrabasic.

to a replacement origin. They should be regarded, on the basis of the highly deformed structures in the talc which are lacking in the delicate actinolites, as unreplaced residues surrounded by later actinolite growths.

The ferromagnesian additions to the feldspathic schist and gneiss walls are regarded as having been transformed from the ultrabasic by the spent steatitizing solutions in the course of their escape from the mineralized zone. In less completely steatitized ultrabasics, these solutions stayed within the intrusive and deposited fibrous magnesian minerals in fractures through the more competent brittle upper part of the dunite or saxonite.

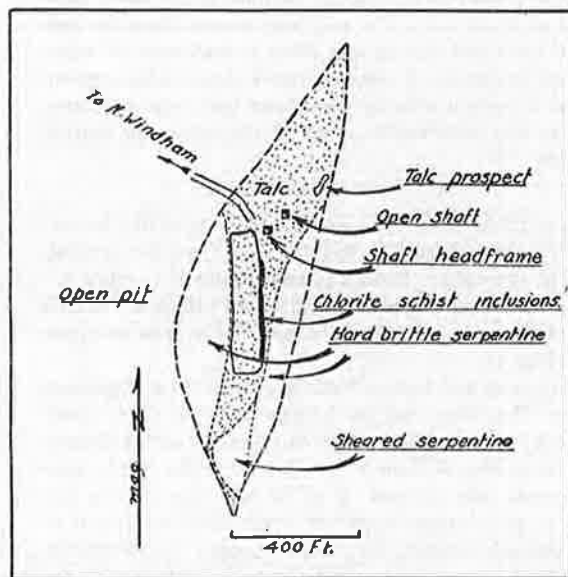


FIG. 4. Map of the ultrabasic at the Windham talc mine. Talc occurs at the north end and along the northward extension of the zone of sheared serpentine at the south end of the mass. The brittle serpentine bordering the sheared rock, inherits the olivine mesh structure, shows only minor deformation and has only siderite and ferrodolomite as introduced minerals.

#### WINDHAM TALC MINE

The Windham talc mine is about  $1\frac{1}{2}$  miles north of Windham village. The north end of the ultrabasic and a sheared zone through the middle have been steatitized. Even some inclusions and the west wall have been changed. Massive blocky serpentine remains only outside the deformed zone and adjacent to the walls at the south end of the intrusive (Fig. 4). Steatitization of the chlorite inclusions indicates subtraction of alumina as well as of magnesium and iron from this mass. Although intensity of the alteration has obscured the details in structural localization of the talc, the evidence is interpreted to indicate changes similar to those in other deposits with a central serpentinized shear zone serving to intensify the alteration along one particular belt.

## RIO TINTO, SPAIN\*

BY DAVID WILLIAMS††

#### INTRODUCTION

THE great pyritic orebodies of the Province of Huelva occur within a broad belt of Palaeozoic rocks, mainly Carboniferous, which separates the pre-Cambrian schists and gneisses of the Sierra Morena from the Tertiary sediments of the southern coastal plains. During Hercynian times the Palaeozoic strata were compressed into a series of approximately east-west folds and subjected to an intense, steeply-inclined flow-cleavage. Numerous sills and dykes of porphyry were then injected along zones roughly parallel to the latitudinal trend of the cleavage, and before the cessation of orogenic pressure the igneous rocks themselves had commonly suffered the impress of schistosity.

Most of the pyritic deposits within the Province are spatially related to the porphyries, the majority of the orebodies being emplaced along or in proximity to the igneous contacts. It seems probable, moreover, that the sulphide mineralization is genetically related to these acid intrusions, and represents a later manifestation of the same magmatic activity that created the porphyries.

Although several deposits still remain concealed beneath a mantle of overlying rocks, the long period of denudation and peneplanation which followed the Hercynian move-

\* Bateman, A. M., Ore deposits of the Rio Tinto (Huelva) district, Spain: Econ. Geol., vol. 22, pp. 569-614, 1927; Edge, A. B., Observations on the pyritic orebodies of Southern Spain and Portugal: Compt. Rendu., Cong. Geol. Internat., Madrid, 1926, vol. XIV, pp. 1207-1230, 1928; Douglas, G. Vibert, On the structural relationships and genesis of the pyritic orebodies of Huelva: Geol. Mag., vol. LXVI, pp. 302-316, 1929; Williams, Gordon, The genesis of the Perrunal-La Zarza pyritic orebody, Spain: Trans. Inst. Min. and Met., vol. XLII, pp. 3-80, 1932; Williams, David, The geology of the Rio Tinto mines, Spain: Trans. Inst. Min. and Met., vol. XLIII, pp. 593-678, 1934; Heim, Arnold, The cupriferous pyrite ores of Huelva, Spain—a tectonic sketch: XVI Int. Geol. Congr. Washington, Copper Resources of the World, vol. 2, pp. 635-648, 1935; de Magnée, L., Observations sur l'origine des gisements de pyrite du Sud de l'Espagne et du Portugal: Congr. Intern. des Mines, VII session. Sect. de Geol. Appliquee, vol. I, pp. 95-104, 1935.

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†† The author is indebted to the Directors of the Rio Tinto Company, Ltd., for permission to publish this paper, and to the Institution of Mining and Metallurgy for granting reproduction of Figs. 2-7.